Reducing Environmental Impacts: Lawn and Garden Care

Case Study

Measuring Environmental Value for Natural Lawn and Garden Care Practices*

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Abstract

Background, Aims and Scope. *Measuring Environmental Value for Natural Lawn and Garden Care Practices* provides a life cycle assessment and impacts valuation methodology to quantify environmental (public health and ecological) and water conservation benefits from natural lawn and garden care practices in Seattle. Seattle Public Utilities (SPU) initiated this study as part of a triple-bottom-line analysis of its Natural Lawn and Garden Care program.

Methods. The study uses life cycle assessment (LCA) methods, including the Carnegie-Mellon Economic Input-Output Life Cycle Assessment (EIOLCA) tool publicly available on the Internet, to inventory pollutant generation from a synthetic nutrients and pesticide approach to lawn and garden care compared against a natural/organic care approach. The study applies US Environmental Protection Agency's TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) climate change, acidification, eutrophication, and human health-criteria air pollutant stressor factors, along with the Lawrence Berkeley National Laboratory's CalTOX risk assessment model's human and ecosystem toxicity potentials to roll up the numerous pollutant quantities into six environmental impact categories (global warming potential, human respiratory disease potential, human toxicity potential, ecological toxicity potential, acidification potential and eutrophication potential). The study develops cost valuation estimates for each impact category to produce a dollar estimate of the environmental cost of the two archetypical lawn and garden care methods.

Results. Lawns and gardens account for 25% of Seattle's land area, so lawn and garden care methods potentially have substantial impacts on the city's land- and water-based ecosystems. LCA methods provide an informative methodology for comparing environmental impacts from lawn and garden care practices. These methods reveal the importance of more natural lawn and garden care practices. They also show that resource extraction and manufacturing impacts of pesticides and synthetic fertilizers dominate their on site use impacts in the case of global warming, but that the reverse holds for human and ecological toxicity, and eutrophication. In addition, releases of particulates, SO_x and NO_x associated with gasoline-powered lawn mowing are nearly an order of magnitude larger than releases of these pollutants as a result of the production of pesticides and fertilizers.

Discussion. The study proceeds by using available data and research to build a desktop model that characterizes and contrasts two archetypical lawn and garden care practices: (1) Petroleum-based fertilizers and pesticides, a gasoline-powered lawn mower, and substantial irrigation to maintain a traditional weed-free, always-green lawn and garden, versus (2) A backyard compost system to provide lawn and garden nutrients, supplemented moderately by purchased non-synthetic soil amendments, an electricity-powered mower, no pesticides, and drought tolerant lawn and garden species having little need for irrigation.

Conclusions. The study concludes that each household converting from synthetic to natural practices produces nearly $75 in annual ongoing public health, ecological, water conservation and hazardous waste management benefits – between $16 and $21 of environmental benefits from reduced use of synthetic fertilizers and pesticides, $8 of environmental benefits for switching from gas to electricity for lawn mowing, $42 in cost savings due to reduced irrigation, and $5 or $6 from lower hazardous waste management costs. There also is a potential one time avoidance of $31 in construction costs resulting from reduced need for storm water detention and diversion capacity.

Recommendations and Perspectives. This study's estimates of environmental value would benefit from comprehensive information on direct exposure to active ingredients in insecticides during their application. Estimates of impacts are based only on volatilization and runoff of active ingredients after application. Furthermore, the study would benefit from estimates of carbon sequestration in soils promoted by natural lawn and garden care techniques, and on the upstream pollutant releases from production of synthetic versus organic fertilizers. All three of these data gaps suggest that the estimated $75 per single family residence for environmental value is probably a lower bound on benefits from natural lawn and garden care versus more traditional pesticide-and-synthetic-fertilizer-based approaches.

Keywords: Environmental externalities valuation; lawn and garden care; life cycle assessment; organic fertilizers; pesticides; synthetic fertilizers; water conservation

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Introduction

Seattle Public Utilities (SPU) initiated a desktop study on the economic value of the environmental (public health and ecological), water conservation, and reduced hazardous waste disposal benefits from natural versus synthetic-nutrient-and-pesticide-based practices for lawn and garden care.[1] The study was part of SPU's triple bottom line analysis of its Natural Lawn and Garden Care program.

We report the results of that study here, including estimated economic values for the reduced impacts to human health and ecosystem well-being associated with the more organic approach versus the traditional approach. We calculated the reduced impacts by using available data and research, plus the opinions of lawn and gardening practice experts at SPU,

[1] See Bormann et al. (2001) for one of the earliest in-depth discussions of the environmental impacts of lawns. That study used the terms 'industrial lawn' and 'freedom lawn' to distinguish conventional lawn care practices from organic-centered practices.

to build a desktop model that characterizes and contrasts two archetypical lawn and garden care practices:

- Petroleum-based fertilizers and pesticides, a gasoline-powered lawn mower, and substantial irrigation to maintain a traditional weed-free, always-green lawn and garden – the conventional practice.
- A backyard compost system to provide lawn and garden nutrients supplemented moderately by purchased non-synthetic soil amendments, an electricity-powered mower, no pesticides, and drought tolerant lawn and garden species having little need for irrigation – the organic-centered practice.

We estimate that average yard and garden area for single-family (SF) households in Seattle is about 405 square meters.[2] On this basis, SF yards and gardens account for about 25% of Seattle's land area. Thus, backyard composting and other components of Seattle's Natural Lawn and Garden Care program have the potential to impact a substantial portion of the city's land- and water-based ecosystems.

1 Results

The organic-centered approach to lawn and garden care saves between $24 and $29 in potential health and ecosystem damages annually per single-family household. Reduced human respiratory and toxicity impacts account for 42% of these environmental benefits, reduced degradation of ecosystems account for 33%, lower greenhouse gas emissions for 23%, and reduced acidification and eutrophication provide the remaining 2%. Reduced synthetic fertilizer and pesticide use is the source of $16 to $21 of the reduced impacts; replacing the gasoline-powered lawn mower with one run by electricity provides the other $8.

Interestingly, the distribution of relative impacts from fertilizer/pesticide use and gasoline-powered mowing is not uniform within each of our six impact categories. Production of fertilizers and pesticides has nearly three times greater global warming and human toxicity impacts than production and use of gasoline for lawn mowing. Also, production of fertilizers and pesticides and their on-site release to the atmosphere and surface waters during and after application to lawns and gardens have ecosystem toxicity impacts that are nearly two orders of magnitude larger than the upstream and on-site ecotoxicity impacts from using gasoline as the energy source for mowing.

It is a different story for emissions of the criteria air pollutants – sulfur oxides (SO_x), nitrogen oxides (NO_x), and particulates – that contribute to respiratory diseases such as asthma and lung cancer. These are nearly nine times greater from using gasoline for lawn mowing than they are from the use of pesticides and fertilizers. However, this difference would not be as large if there were reliable data available to account for particulate releases during yard and garden applications of fertilizers and pesticides. As it is, data are available on indirect contact through volatilization of active ingredients into the atmosphere and runoff into surface waters, but little information is available on direct skin contact and inhalation of particulates during application.[3]

In addition to reduced public health and ecosystem impacts, natural lawn and garden care practices yield annual savings in irrigation water worth $42 on the basis of avoided marginal costs for source water filtration. Natural practices also avoid between $5 and $6 in hazardous waste management costs due to SPU not having to manage disposal of partially-filled pesticide containers. Finally, the increased infiltration, evaporation and rainwater retention capabilities of the natural lawn and garden potentially provide a one time avoidance of stormwater detention capacity worth over $31.

2 Discussion

Calculation of Economic Values for the Ecological and Public Health Benefits Provided by a Healthy Yard & Garden Ecosystem

Based on our conventional vs. organic-centered archetypical characterizations for lawn and garden care, we built a life cycle model that estimates environmental releases of chemical compounds and nutrients from production and use of fertilizers and pesticides, the human health and ecological impacts caused by these releases, and the economic costs imposed by their health and ecosystem impacts. In addition, we used results from Sivaraman and Lindner (2004) to account for impacts from the energy source chosen for lawn mowing.

Our model's lawn fertilization rate is based on 1.8 kilograms of nitrogen (N) annually per 93 square meters of lawn, with a target NPK (nitrogen-phosphorous-potassium) ratio of 3-1-2, distributed over 3 or 4 applications, as recommended by Washington State University (McDonald 1999). The conventional treatment gets all lawn N from synthetic fertilizers using two applications of a weed and feed product and two applications of a synthetic fertilizer without any herbicide constituents.[4] The other two applications are with synthetic fertilizers containing highly soluble nutrients. In addition, the conventional treatment fertilizes gardens with a product that also provides some insect control, further controls garden insects with insecticide, controls garden weeds with herbicide[5], controls lawn weeds with a weed and feed product, and uses insecticide to control Crane fly.

[2] Based on King County Assessor's Office data on the unbuilt portion of single-family house parcels in Seattle.

[3] In a recent article in this journal, Geisler et al. (2005) explore the implications of uncertainties and variabilities in life cycle inventory flows and characterizations for two plant-protection products. Their study concludes that these uncertainties prevent determination of which product is environmentally preferable. In the case of the two lawn and garden care practices compared in this study, uncertainties and data gaps mostly accrue to the detriment of the environmentally preferable lawn and garden method. Thus, removal of data gaps and reduction of uncertainties likely would reinforce the conclusions of our study.

[4] Surveys conducted by King County support the assumption that two of the conventional practitioner's four fertilizations are with weed-and-feed products.

[5] The specific products we model the two archetype households using are: Conventional – 2 applications of Scotts Turf Builder Plus 2, 2 applications of Scotts Lawn Pro Super Turf Builder 30-3-3, 1 application of Scotts Bug-B-Gon Granules, 6 applications of Bayer 2 in 1 Rose and Flower Care, and 3 applications of Scotts Garden Weed Preventer; Organic-Centered – 2 applications of Espoma Organic 18-8-6.

By contrast, the organic-centered approach gets 50% of lawn N from grasscycling and the rest from 2 applications of a non-synthetic (often termed 'organic') fertilizer that has low nutrient solubility. This treatment uses compost from the backyard compost bin to fertilize gardens, and manages that compost bin so as to avoid anaerobic conditions and, thus, prevent inadvertent generation of methane and ammonia gases. Furthermore, the organic-centered treatment uses no pesticides on lawn or gardens.

The conventional treatment uses 903 liters of irrigation water annually per square meter of lawn and garden. This is distributed across the year as 3.0 centimeters per week for the lawn during peak irrigating season and 2.9 for the garden; and 0.33 and 0.43 centimeters per week for lawn and garden, respectively, during the off-peak season. On the other hand, the organic-centered treatment uses 8.1 liters of irrigation water annually per square meter of lawn, all distributed during peak season at 0.05 centimeters per week. This treatment uses 41 liters of irrigation water annually per square meter of garden. This is distributed as 0.20 centimeters per week during peak season and 0.03 during off-peak season.

Other model parameters include that the conventional lawn and garden care practitioner disposes of half of unused pesticides in weekly garbage collection and the other half at Seattle's household hazardous waste facility, that practitioners of both treatment methods save unused fertilizers for use the following year, that rainwater runoff rates for the conventionally treated lawn and garden are about 20 percentage points higher than for the lawn and garden of the organic-centered practitioner[6], that the conventional practitioner mows his lawn weekly using a gasoline engine mower while the organic-centered practitioner mows the lawn with a mower powered by electricity. In order to hold constant impacts from mowing frequency, we assumed the organic-centered practitioner also mows weekly.

Table 1 provides further detail characterizing the conventional and organic-centered methods. For example, the conventional practitioner's annual fertilizer application rate amounts to 7.1 kilograms of nitrogen on his lawn, a rate of 196 kilograms per hectare per year. This is well within the 112 to 280 kilograms per hectare range of nitrogen application amounts found in the survey literature.[7] This treatment method's lawn irrigation rate is 3.0 centimeters per week during the thirteen week peak watering season, somewhat above the oft-repeated summer season lawn watering maximum of 2.5 centimeters weekly.[8] The conventional practitioner's irrigation total equals 67% of Seattle's annual rainfall.

Table 1: Characterization of conventional and organic-centered lawn and garden care practices

	Conventional	**Organic-Centered**
Lawn Area	364	243
Garden Area	41	162
Total (square meters)	405	405
Lawn Fertilization Amounts (kilograms)		
Nitrogen (N)	7.1	2.4
Phosphorus (P)	0.7	1.0
Potassium (K)	0.7	0.8
Garden Fertilization Amounts (kilograms)		
Nitrogen (N)	0.7	0
Phosphorus (P)	1.1	0
Potassium (K)	0.5	0
Pesticide Toxic Constituent Applications (kilograms)		
2,4-D	0.15	0
MCPP	0.15	0
Carbaryl	0.45	0
Disulfoton	0.06	0
Trifluralin	0.05	0
Pesticide Toxic Constituent Disposal (kilograms)		
Carbaryl	0.03	0
Disulfoton	0.005	0
Trifluralin	0.05	0
Pesticide Products Disposal (kilograms)	4.16	0
Annual Irrigation Water Use (liters)		
Lawn	222,605	1,484
Garden	24,734	6,596
Total	**247,339**	**8,080**
Annual Rain Water Runoff (liters)		
Lawn	266,432	133,216
Garden	27,754	74,009
Total	**294,186**	**207,225**
% Households in Combined Sewer System Areas	25%	25%

The conventional practitioner's annual lawn pesticide applications total 0.15 kilograms each for the herbicides 2,4-D and MCPP, and 0.45 kilograms of carbaryl for Crane fly. This is an annual pesticide application rate of 20.7 kilograms per hectare, a reasonable amount for the high-use end of the spectrum based on an estimated application between 6 and 8 kilograms annually for the average hectare of maintained lawn.[9] The conventional treatment's garden pesticide applications total 0.06 kilograms of disulfoton and 0.05 kilograms of trifluralin annually, an application rate that amounts to 28.7 kilograms annually per hectare of garden area.

[6] See Waterfall (1998) for estimated rainwater runoff rates for various surfaces.

[7] See, for example, the surveys summarized by the article 'Nitrate Leaching Potential from Lawns and Turfgrass,' in Scheuler and Holland (2000).

[8] See Nielson and Smith (2005, p. 105) for an example of the recommendation that lawn watering should total no more than 2.5 centimeters per week.

[9] See 'Urban Pesticides: From the Lawn to the Stream,' in Scheuler and Holland (2000).

(i) Six Life Cycle Impact Categories for Measuring and Monetizing the Effects of Conventional and Organic-Centered Lawn and Garden Care Practices

The six environmental impact categories we included in our analysis and the impact cost estimates for each category's numeraire are[10]:

1) Global warming potential. This environmental impact category characterizes the increase in the greenhouse effect due to emissions generated by humankind. Estimates of the dollar cost imposed by emissions of a Mg of greenhouse gases (GHGs), measured as CO_2 equivalents (eCO_2), range from $1 per Mg eCO_2, a recent price for emissions traded under voluntary GHG emission limitation agreements in the US, to $20 per Mg based on emissions trading in the European Union under mandatory GHG reduction objectives. For a long-term perspective Seattle City Light (SCL) uses a mitigation cost of $40 per Mg for fossil CO_2 emissions from electricity generation. For consistency with SCL, SPU uses $40 per Mg of CO_2 equivalents to value the benefits associated with reductions in GHG emissions.

2) Human health impact of certain criteria air pollutants. The effects of certain criteria air pollutants on human health constitute the second life cycle impact category. This category measures impacts in terms of disability-adjusted life year (DALY) losses due to certain types of air pollution. The air pollutants of concern in this impact category are solid and liquid particles commonly found in the air, including coarse particles known to aggravate respiratory conditions such as asthma, and fine particles that can lead to more serious respiratory symptoms and diseases such as lung cancer. Specifically, the US EPA criteria air pollutants that cause or exacerbate these human health effects are nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulates. DALYs measure health losses from these air pollutants by accounting for years of life lost and years lived with disability, adjusted for the severity of the associated unfavorable health conditions. We measured the economic cost of a DALY by the Bureau of Economic Analysis' Seattle-Tacoma-Bellevue Metropolitan Statistical Area average wage per job in 2002 of $44,050. Inflating this 2002 annual wage to 2005 dollars yields our cost valuation for a DALY of $46,586.

3) Human toxicity potential (HTP). EPA (2002) in its TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) software developed toxicity equivalency potentials for numerous chemical compounds. These toxicity ratings are intended to rank the relative health concerns associated with various chemicals from the perspective of a generic individual in the U.S.[11] As part of a currently-underway process to revise and update TRACI, HTPs developed by Lawrence Berkeley National Laboratory's CalTOX risk assessment model (version 4.5)[12] are being considered. The CalTOX HTPs may provide important improvements over those in the initial version of TRACI, and are therefore the HTPs used in this study.[13]

Toxicity potentials allow us to sum up the impact of each pollutant into human toxicity scores. These scores are customarily expressed as toluene equivalents for non-cancer health impacts and benzene equivalents for cancer health impacts. We used the health impacts from air emissions of mercury (Hg) to monetize the HTP toxicity scores.[14] Our estimate of monetary costs for air emissions of mercury are from a peer-reviewed study sponsored by the Northeast States for Coordinated Air Use Management (NESCAUM) (Rice and Hammitt 2005). This study evaluated neurological and possible cardiovascular health impacts from exposure to methylmercury through fish consumption, where atmospheric releases of mercury result in depositions of mercury in water bodies within and bordering the U.S. These depositions lead to increases in methylmercury concentrations in fish.

The NESCAUM study evaluated three main health effects from methylmercury exposure – neurological decrements associated with intrauterine exposure, myocardial effects associated with adult exposure, and elevated childhood blood pressure and cardiac rhythm effects associated with *In Utero* exposure. We used the economic cost estimated in the study for only the first effect. The decrease in cognitive

[10] The brief explanations given here for each impact category are from Lippiatt (2002). See Bare et al. (2003), US EPA (2002a) and Lippiatt (2002) for a more detailed explanation of the specific pollutant and toxic stressors, the relative weightings for each stressor that are used to compute the summary score for each impact category, and the specific endpoint impacts each category subsumes. The stressor weights we used are based on EPA's TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) model, except that human and ecosystem toxicity potentials are from the Lawrence Berkeley National Laboratory's CalTOX risk assessment model. The TRACI model is described in US EPA (2002a). A description of the CalTOX model is available at http://eetd.lbl.gov/IED/ERA/caltox/index.html.

[11] See Toffel and Marshall (2004) for a comprehensive assessment of toxicity equivalency potential weighting methods. See Dutilh and Koudijs (1998) for an earlier discussion on toxicity equivalency potentials.

[2] See the description of CalTOX at http://eetd.lbl.gov/IED/ERA/caltox/index.html.

[13] EPA is also evaluating the UNEP-SEATAC harmonization model HTPs. Those toxicity scores were not available to the authors when this study was conducted.

[14] We initially thought we would use the Minnesota Public Utilities Commission quantifications of the externalized environmental costs of criteria air pollutant emissions, in particular lead, associated with electricity generation to measure the human health costs of toxics. See Minnesota PUC (1996 and 2001). The Commission's cost estimates, developed in 1995-96 under direction of the Minnesota legislature, were challenged in court, and affirmed by the Minnesota Court of Appeals. Minnesota's Supreme Court in 1998 denied a requested review of the Appeals Court's affirmation. The MN PUC's externalized cost for lead in urban areas was $3,175 per Mg in 1995 dollars.
However, we instead decided to use the mercury estimate described in the text for three reasons. First, the mercury estimate is based on a well-designed and rigorous public-agency sponsored study released in 2005 on the health effects across the US of mercury emissions from coal-fired power plants. This is a more timely and broad-based study than the early 1990s lead study on which the MN PUC environmental cost estimates were based. Second, the MN PUC estimates are based on a private utility (Northern States Power) funded study. Northern States Power (NSP) was a party to the adversarial proceedings in the MN PUC docket on externality costs. Third, and perhaps most importantly, the NSP study limited its assessment of damages to those incurred within less than 100 miles of any of the private utility's power plants. This limitation on geographic scope caused the study's authors to admit that their damage estimates "would likely have been significantly higher if we had expanded the scope." (Banzhaf et al. 1996, pp. 399–400).

ability as a result of intrauterine exposure to methylmercury is well documented and understood, whereas research on the other two health effects is not yet as extensive or thoroughly peer-reviewed.

Further, we used the NESCAUM study's health cost estimate based on the assumption of a neurotoxicity threshold equal to EPA's reference dose (RfD) for mercury.[15] On this basis the health costs from atmospheric releases of mercury amount to $4.6 million per Mg released.[16] Inflating the $4.6 million estimate in 2,000 dollars to 2,005 dollars yields a cost of $5.2 million per Mg of atmospheric releases of mercury. We applied this cost to our human toxicity scores by using the TRACI non-cancer weightings for air emissions of toluene versus mercury, after converting benzene cancer equivalents to toluene non-cancer equivalents by multiplying benzene cancer equivalents by 21,100.[17]

4) Ecological toxicity potential (ETP). EPA in its initial TRACI software also developed toxicity equivalency potentials for chemicals that measure the relative potential for these compounds, when released into the environment, to harm terrestrial and aquatic ecosystems. As with HTPs, EPA is currently updating the ETPs in TRACI. The CalTOX model's ETPs are under consideration for that update, and this study, thus, used the CalTOX 4.5 ETPs to weight the ecosystems toxicity of chemical releases in terms of 2,4-D equivalents.

We estimated the toxicity cost to plants and wildlife from application of a kilogram of 2,4-D herbicide at $3.62. This is an updated estimate from Joe Kovach, Integrated Pest Management Program at Ohio State University, based on his research originally reported in Kovach et al. (1992) on putting an environmental price to pesticide use.[18] The estimate includes costs for impacts on fish, birds, bees and beneficial arthropods, but not the estimated costs developed by Kovach for impacts on human health as a result of groundwater contamination. That human health cost is captured in the human toxicity potential impact category.

5) Eutrophication potential. This impact category characterizes the addition of mineral nutrients to the soil or water. In both media, the addition of large quantities of mineral nutrients, such as nitrogen and phosphorous, results in generally undesirable shifts in the number of species in ecosystems and a reduction in ecological diversity. In water, it tends to increase algae growth, which can lead to lack of oxygen and therefore death of species such as fish. Our estimate of the impact cost of releases of nutrifying compounds is based on EPA's cost-effectiveness analysis for the NPDES regulation on effluent discharges from concentrated animal feeding operations. That analysis estimated that costs up to $4.41 per Mg of nitrogen removed from wastewater effluents were economically advantageous (US EPA 2002b, p. E-9).

6) Acidification potential. This impact category characterizes the release of acidifying compounds from human sources, principally fossil fuel and biomass combustion, which affect trees, soil, buildings, animals and humans. The main pollutants involved in acidification are sulfur and nitrogen compounds – e.g., sulfur oxides, sulfuric acid, nitrogen oxides, and ammonia (NH_3) – along with hydrochloric acid (HCL). We estimated the cost of releases of acidifying compounds based on the spot market price for SO_2 emissions permit trading under the US Clean Air Act's cap and trade program. US EPA's March 2005 spot market auction for emissions permits resulted in a clearing price of $761 per Mg SO_2.[19]

Based on the fertilizer, pesticide and water usage rates shown in Table 1, we calculated environmental impacts for these six categories from upstream resource extraction and manufacturing of the fertilizer and pesticide products, as well as from their usage and release into the household's lawn, garden and surrounding ecosystems.[20] We used the Carnegie-Mellon Economic Input-Output Life Cycle Assessment (EIO-LCA) model to inventory the environmental releases from pesticide and fertilizer product manufacturing. We used peer-reviewed literature to estimate likely solubility, persistence, and release rates into the air and water of the nutrients and active toxic ingredients in any fertilizers and pesticides used on the conventional or the organic-centered lawn and garden.

We used a peer-reviewed life cycle study (Sivaraman and Lindner 2004) of gasoline-, battery-, and electricity- powered lawn mowers to estimate relative impacts from lawn mower use. We used the on-site emissions from that study for a gasoline-powered lawn mower meeting US EPA's Phase 2 standards. We also relied on that study's estimates for the upstream emissions associated with energy resources exploration, refining, production and distribution – for gasoline for the mower used by the conventional practitioner and for the electricity used to power the organic-centered practitioner's mower.

Sivaraman and Lindner did not include impacts from production of the mowers themselves. Their study was focused on comparing environmental impacts of different power sources for lawn mowers. To that end they assumed differ-

[15] RfD is that dose below which it is assumed there is no health impact from exposure to a potentially toxic substance. EPA's oral RfD for methylmercury is 0.1 micrograms per kilogram of body weight per day. The reference dose is the highest daily intake that is thought to be safe, as derived from animal experiments and extrapolated to humans. RfDs are calculated for chronic ingestion and are based only on non-cancer effects.

[16] By comparison, the no threshold cost is estimated at $11.6 million per Mg, 2.5 times higher. (Rice and Hammitt 2005, p. 193).

[17] See Lippiatt (2002) and Curran et al. (2002) for derivation and discussion of the 21,100 equivalency factor.

[18] Pesticide wash-off may be higher in a hilly urban environment than in a flat agricultural field. To the extent that Kovach relied on agricultural crop studies, his estimate of the cost to non-target plants and wildlife may underestimate the cost of pesticide applications in an urban environment.

[19] Data on US EPA auctions of acid rain allowances is at http://www.epa.gov/airmarkets/auctions/index.html.

[20] We did not attempt to estimate the downstream environmental impacts from the conventional practitioner's disposal of unused pesticide products. Nor did we attempt to estimate the increase in carbon sequestration in soils that is likely to be associated with the organic-centered practitioner's use of organic composts and natural lawn and garden care practices.

ences among upstream raw materials and manufacturing impacts for the different types of lawn mowers would be negligible when averaged out over the lifetime of the mowers. We are mainly interested in the impact differential between the organic-centered and conventional lawn and garden care practices. So we adopted this same assumption for our study. Thus, the numerical estimates provided in this study for environmental impacts and associated economic costs exclude impacts from manufacture of the lawn mower product itself.

(ii) Human toxicity ratings and volatilization/runoff levels for the conventional practitioner's releases of pesticides in his yard and garden

Table 2 summarizes the information we gathered on relative human toxicity and surface water mobility for the various toxic constituents in pesticides used for the conventional treatment. Toxicity ratings for the toxic constituents of pesticides used for this treatment method range from a low given by the non-cancer toxicity impacts from atmospheric releases of carbaryl, to a high given by the cancer toxicity impacts from atmospheric releases of 2,4-D.

Human and ecological toxicity impacts from exposure to pollutants in air and water are a function of both relative toxicity and amount to which one is exposed. First, we examine exposures through water bodies. We calculated the amount of a pesticide's active ingredients that runoff into streams and lakes according to the expected mobility of each ingredient in the soil based on the Surface Water Mobility Indices (SWMI) shown in Table 2. The SWMI for each active ingredient is a function of that ingredient's soil sorption coefficient and its persistence as measured by its soil half life.[21] The SWMI corrects for differences in persistence and soil binding among the different active chemical compounds.

[21] Chen et al. (2002) provides the formula for this calculation. The Oregon State University Extension Pesticide Properties Database provides the soil sorption coefficients and soil half life parameters that are needed to calculate the SWMI for each ingredient.

We assume that 100% of the runoff amounts have the potential for human and ecosystem species exposures through water. We determined the runoff amounts from regression results in Chen et al. (2002). These regressions estimate pesticide concentrations in surface water based on SWMI, pesticide usage rate, and total area of a drainage basin or watershed. By normalizing the runoff amounts for each active ingredient against a high-end assumption for 2,4-D amounting to 10% of the 2,4-D application rate, we were able to avoid having to estimate drainage basin or watershed areas.

Yates (1995) found that up to 7.6% of applied 2,4-D leached when pesticides with that ingredient were applied on soil with little clay content. Runoff amounts dropped below 1% in soils that contained some clay to adsorb the pesticide. Smith (1995) found that over a 25-day period following treatment of test plots, 8% of the applied 2,4-D, MCPP, and dicamba left the test plots in runoff, along with an average of 42% of the naturally occurring rainfall water. In his USGA sponsored study, Petrovic (1995) tested experimental fairways composed of sand, sandy loam and silt loam. MCPP runoff concentrations were between 51% and 62% in the sand fairways, versus 0.4% to 1.3% from fairways grown on the other soil types.

Based on this reported variability in runoff rates for different soil types, weather conditions, and grass turf conditions, we selected 10% runoff as the high-end, 95th percentile 2,4-D runoff potentiality for a conventionally treated lawn and garden with low soil sorption capacity. On this basis we estimate that average runoff rates for the toxic constituents of pesticides vary between 0.02% and 7.43%, as shown in **Table 3**. These estimates are based on Chen's regression results for time-weighted mean concentrations. The specific figure for each ingredient depends on its SWMI relative to the SWMI for 2,4-D.

Chen also provided regression equations for 95th percentile concentrations – that is, the estimated concentration which we expect will be higher than 95% of actually observed concentrations. These 95th percentile estimated runoffs vary between 0.05% and 17.32% across the different constituents.

Table 2: Pesticide active ingredient human toxicity and surface water mobility ratings [a]

Active Ingredient	Memo: EPA Reference Dose [b]	Air Release – Cancer Toxicity	Air Release – Non-Cancer Toxicity	Surface Water Release – Cancer Toxicity	Surface Water Release – Non-Cancer Toxicity	Surface Water Mobility Index [c] (SWMI)
2,4-D	0.01	3.47E-01	2.16E-03	4.98E-03	1.90E-05	0.66
Carbaryl	0.01	6.29E-05	3.27E-08	2.26E-02	5.77E-06	0.37
Disulfoton	0.00013	0.00E+00	1.69E-01	0.00E+00	5.08E-02	0.33
MCPP	0.001	0.00E+00	3.12E-01	0.00E+00	3.34E-04	0.8
Trifluralin	0.025	1.11E-02	1.95E-04	4.00E-03	6.72E-05	0.1
Mercury	0.00001	0.00E+00	1.00E+00	0.00E+00	9.44E+00	

[a] Toxicity ratings shown in the table for active ingredients of pesticide products are relative to the non-cancer toxicity potential rating for atmospheric releases of mercury.

[b] EPA index number that represents mg/kg body weight per day that humans can ingest with no effect.

[c] The SWMI is a function of pesticide's half life in soil and its soil sorption coefficient. We used the SWMI to estimate pesticide wash-off rates based on empirical data provided in Chen et al (2002).

Table 3: Pesticide active ingredient runoff rates

Active Ingredient	Estimated Mean Runoff	Estimated 95th Percentile Runoff	Surface Water Mobility Index [a]
2,4-D	4.27%	10.00%	0.66
Carbaryl	0.80	1.92	0.37
Disulfoton	0.58	1.38	0.33
MCPP	7.43	17.32	0.8
Trifluralin	0.02	0.05	0.1

[a] The SWMI is a function of pesticide's half life in soil and its soil sorption coefficient. We used the SWMI to estimate pesticide wash-off rates based on empirical data provided in Chen et al (2002).

Next, we examine exposure through the air. Human and ecological toxicity impacts from exposure to airborne pesticides are a function of atmospheric releases of active ingredients in the pesticides. The amount of these releases, in turn, depends on volatilization rates for those ingredients after their application to lawns and gardens. As explained in Kenna (1995), volatilization of a pesticide's active ingredients depends on many factors – air temperature, air movement, vapor pressure rating of the ingredients, the water solubility of the particular form of the active ingredient in the pesticide formulation, the particular combination of ingredients in the pesticide formulation, and application specific factors such as whether the lawn or garden is irrigated immediately after the application.

In her study for the US Golf Association (USGA) Yates (1995) found that between 0.43% and 1.05% of 2,4-D volatilized, while no more than 0.05% of carbaryl vaporized in the air after application. A USGA-sponsored study by Cooper, et al. (1995) found volatilization over a two-week period following application to range from less than 1% (but greater than 0.5%) of amounts applied for MCPP to 13% for trichlorfon. Because of the complexities involved with predicting volatilization rates for the active ingredients in the conventional practitioner's pesticides, we made the simplifying assumption that on average 0.5% of the active ingredients in pesticides applied on lawns and gardens volatilize and lead to potential human and ecosystem exposures through the air.

Last, an important data gap is that little information is available on direct skin contact and inhalation of particulates during application. Thus, we could not calculate impacts from exposure to active ingredients via direct bodily contact with, or inhalation of, the liquid or solid form pesticides during application or from contact with plants, trees or grass after pesticide application. As a result, we have not addressed a major route for potential exposure to the active ingredients in pesticide formulations, and our health impacts for the conventional practitioner's pesticide applications may be underestimated.

(iii) Estimated environmental impacts from lawn mowing energy source and from pesticide and fertilizer manufacture & use

As mentioned in Subsection (i), we used the Carnegie-Mellon EIO-LCA online model to estimate upstream environmental releases from pesticide and fertilizer product manufacturing. We used the pesticide active ingredient runoff and volatilization rates explained in Subsection (ii), along with TRACI ecological toxicity ratings, to calculate ecological impacts from the conventional treatment's use of pesticides. We also used runoff and volatilization rates and the human toxicity ratings from Subsection (ii) to calculate human toxicity impacts from conventional pesticides use.

To calculate the eutrophication impact of fertilizer use, our model posits that between 1% and 15% of the conventional treatment's nutrients run off into streams and lakes versus between 0.05% and 0.75% for organic-centered treatment nutrients. The organic-centered nutrient runoff rates are much lower due to organics fertilizers being less than 10% water soluble. By comparison, conventional synthetic fertilizers likely are at least 80% soluble.[22]

We base the conventional treatment's runoff rates on USGA studies. Yates (1995) found nitrogen leaching rates between 0.3% and 1.7%. Bowman et al. (1995) found that over 15% of applied nitrogen leached from Bermuda grass irrigated with fresh water. Starrett and Christians (1995) found that about 10% of nitrogen leached within a few hours of application under heavy irrigation.

We used the study by Sivaraman and Lindner (2004) to measure the life cycle impacts of the energy source for lawn mowing. We did not investigate the impacts from lawn mower manufacturing. Nor did we quantify the on site and neighborhood impacts from relative noise levels for gasoline- versus electricity-powered lawn mowers. However, the latter are known to reduce mowing noise by 50% or more. We also did not evaluate the risk of electric shock if the cord is severed while the electric mower is being used.

Table 4 shows environmental impact potential ratings from the lawn and garden care practices used by the two treatment alternatives. Within each impact category, Table 4 shows that impact category's releases during upstream raw materials extraction, refining and manufacture into fertilizers and pesticides. In addition, the table shows impacts from releases into the atmosphere and into surface waters from pesticide and fertilizer volatilization and runoff after application on lawns and gardens. Finally, the table shows combined upstream and onsite releases associated with the fuel sources for lawn mowing – gasoline for the conventional practitioner and electricity for the organic-centered practitioner.

The ranges for human and ecological toxicities shown on the table reflect the difference between using regression mean or 95th percentile estimates for pesticide runoff calculations.

[22] See McDonald (1999).

Table 4: Impacts of pesticide, fertilizer and lawn mower fuel manufacture and use

	Conventional	Organic-Centered
Global Warming (eCO_2 kilograms)		
– upstream impact (pesticide/fertilizer)	163.5	67.6
– upstream/on site impact (mower fuel)	57.4	0.01
Human Toxicity (eMercury 10^{-3} kilograms)		
– upstream impact (pesticide/fertilizer)	0.26	0.10
– on site air (pesticides)	0.56	0
– water runoff (pesticides)	0.14–0.32	0
– upstream/on site impact (mower fuel)	0.35	0
Criteria Air Pollutants (microDALYs)		
– upstream impact (pesticide/fertilizer)	9.96	3.76
– upstream/on site impact (mower fuel)	86.44	3.47
Ecological Toxicity (e2,4-D kilograms)		
– upstream impact (pesticide/fertilizer)	0.09	0.04
– on site air (pesticides)	0.97–1.04	0
– water runoff (pesticides)	0.76–1.93	0
– upstream/on site impact (mower fuel)	0.03	0
Eutrophication (eNitrogen kilograms)		
– upstream impact (pesticide/fertilizer)	0.02	0.01
– water runoff (fertilizers)	0.19–2.79	0.005–0.07
– upstream/on site impact (mower fuel)	0.09	0.005
Acidification (eSO_2 kilograms)		
– upstream impact (pesticide/fertilizer)	0.60	0.24
– upstream/on site impact (mower fuel)	0.36	0.01

These ranges for pesticide active ingredient runoff are given in Table 3. The range of estimates for eutrophication is based on the ranges for nutrient runoff listed at the beginning of this subsection.

We should also note that the Carnegie-Mellon EIO-LCA model we used to estimate upstream releases is product specific only at the aggregated 491 industrial sectors level. This means that resource extraction, resource refining, and product manufacturing impacts for synthetic and non-synthetic fertilizers are calculated as being the same for both fertilizer types. Thus, it is only the difference in purchased fertilizer quantities, not in fertilizer types, that is reflected in the conventional versus organic-centered differences in upstream impacts. Especially for global warming impacts this means the estimates shown in Table 4 likely understate the benefits of organic-centered lawn and garden care practices. The organic-centered practitioner's fertilizers in fact are not fossil fuel based.

Several observations are worth noting about the impact scores shown in Table 4. First, gasoline lawn mowers have greenhouse gas (GHG) and human toxicity impacts that are only 35% and 37%, respectively, of the GHG and human toxicity impacts from the conventional practitioner's level of pesticide use. Lawn mowing has an even lower toxicity impact on ecosystems compared with the ecotoxicity impacts of pesticide use. At the same time, gas-powered mowing has 8.7 times greater potential for causing human health impacts from particulates than resource extraction and manufacturing for conventional fertilizers and pesticides do.

Second, impacts shown for the organic-centered treatment, other than the greenhouse gas impacts for reasons discussed above, typically are at least an order of magnitude smaller than for the conventional treatment. Furthermore, the impact from SO_x, NO_x, and particulates released by the generation of electricity to power the electric lawn mower used by the organic-centered practitioner is 25 times lower than the impact of the gasoline that powers the conventional mower. This difference reflects, in part, the typically more stringent pollution controls for electricity generating facilities compared with gasoline-powered lawn mowers, even mowers meeting the latest EPA guidelines.

Finally, we compare and summarize the environmental impacts shown in Table 4 by means of estimates for their relative economic costs. **Table 5** provides an estimate of the economic cost for each environmental impact shown in Table 4. One conclusion is immediately apparent from Table 5 – the economic costs of conventional lawn and garden care practices, including impacts from using gasoline for lawn mowing, are nearly an order of magnitude larger than the costs of organic-centered practices. It is also interesting that ecological toxicity costs are more sensitive to pesticide runoff rates than are human toxicity costs. As shown in Table 5, ecotoxicity costs go up 67%, while human toxicity costs increase just 14% when pesticide runoff rates increase 140%.

Lastly, we note that estimated costs from the acidification and eutrophication[23] impacts of conventional fertilization, pesticide and lawn mowing practices are small in comparison to their global warming, human health or ecosystem health impacts costs. It was not the intent of this study to assess impacts of actual lawn and garden care practices in Seattle. However,

[23] The $4.41 per Mg for nitrogen releases to water used by EPA as the cutoff point on spending to remove nutrifying compounds from effluent discharges from confined animal feeding operations may underestimate the public health and ecological costs of eutrophication from fertilization releases in an urban area by a substantial amount.

Table 5: Environmental costs of pesticide, fertilizer and lawn mower fuel manufacture and use (US dollars per household per year)

	Conventional	Organic-Centered
Global Warming	$8.77	$2.77
Human Toxicity	6.81–7.78	0.54
Criteria Air Pollutants	4.49	0.34
Ecological Toxicity	6.68–11.18	0.13
Eutrophication	0.001	0.000
Acidification	0.74	0.19
Total	**$27.49–$32.97**	**$3.97**

it should be pointed out that small impacts from a single household can be substantial when amplified to a regional scale.

3 Conclusions

In sum, we estimate that a SF parcel using the organic-centered approach to lawn and garden care saves between $23.52 and $29.00 in non-market environmental costs per year compared to a SF parcel using the conventional approach.

We also note several other important benefits from organic-centered lawn and garden care practices. First, based on just the marginal cost of source water filtration, the organic-centered treatment avoids using irrigation water that has an annual marginal cost to SPU of at least $42.24.[24] Further, the organic-centered practitioner's not using pesticides and, thus, not disposing of any pesticide product residues, avoids $5.46 in annual hazardous waste management costs to SPU.[25] Finally, the increased infiltration, evaporation, and rainwater retention capabilities of organically-treated lawn and gardens potentially provide a one-time avoidance of stormwater detention capacity worth $31.46.[26]

Together the pollution prevention, water conservation and runoff minimization, and hazardous waste minimization benefits from every household that employs organic-centered lawn and garden care practices reduce annual triple bottom line costs by $75 compared with more traditional water, fertilization and pesticide intensive practices.

[24] This marginal cost estimate recognizes no fish habitat or other ecosystem value for greater stream flows as a result of reduced irrigation water usage. It should perhaps be considered a lower bound estimate for the economic value of reduced irrigation.

[25] Elimination of pesticide use also avoids the environmental costs from the disposal of partially used containers of pesticides in either the municipal or the hazardous solid waste streams. These downstream environmental costs were not examined in this study.

[26] This assumes that increased infiltration and retention of rainwater on the organic-centered practitioner's property does not result in any substantially increased infiltration of rainwater into the sewers in partially separated drainage system areas due to leaky sewer pipes between the house sewer outlet and the street sewer connection.

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